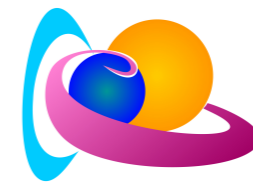


SPACE WEATHER INTRODUCTORY COURSE



Collaboration of



Solar-Terrestrial Centre of Excellence



Koninklijke luchtmacht



Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu



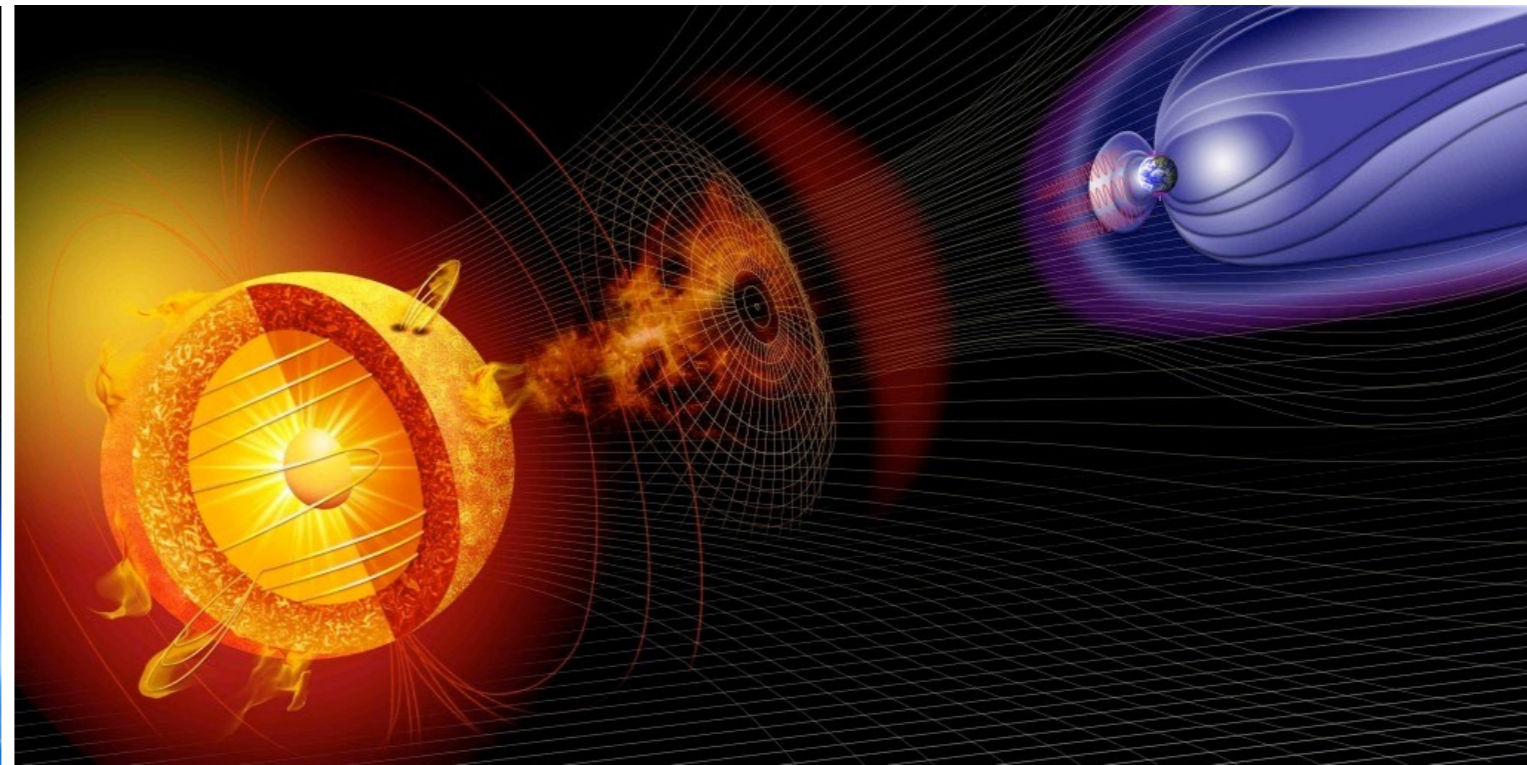
SPACE WEATHER

Introduction

Petra Vanlommel

Space Weather

The Sun's energy impacting earth's atmosphere and magnetic shield.



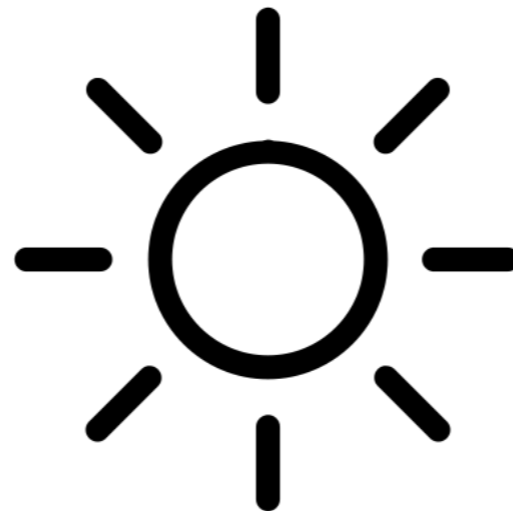
THE SUN AS A BALL OF ENERGY

The sun emits continuously energy which is expelled to outer space in the form of electromagnetic waves and moving plasma.

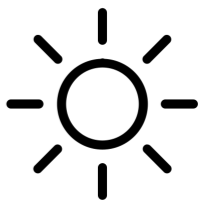
E.M. WAVES



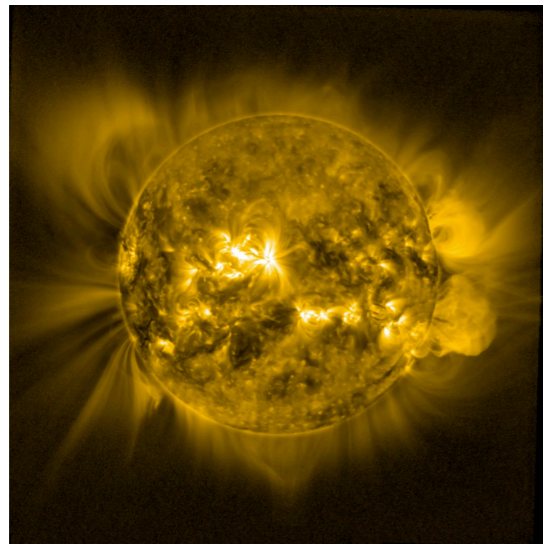
PLASMA



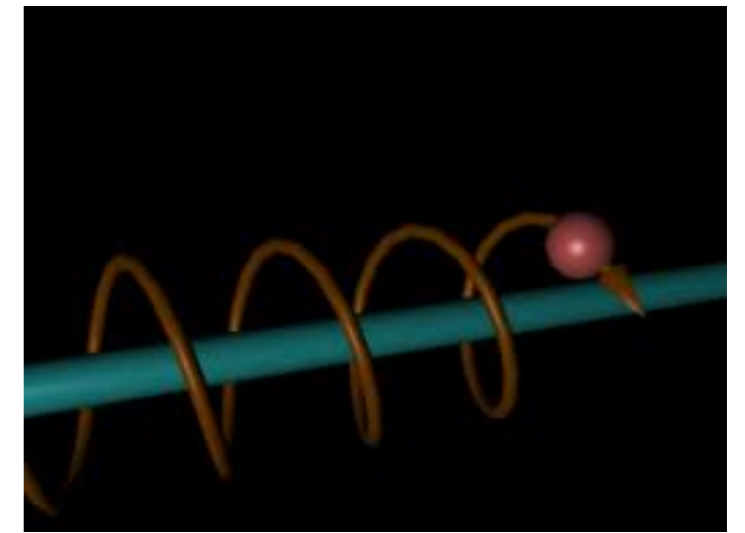
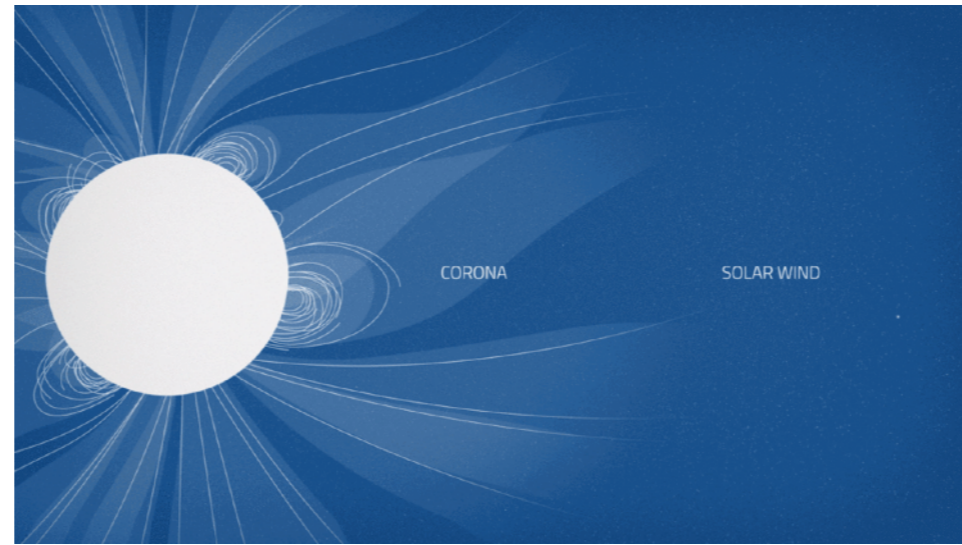
SPACE CLIMATE



The emitted energy creates a space climate that has 2 seasons: a more active and a less active. This seasonal variation is called the solar cycle and takes around 11 years.



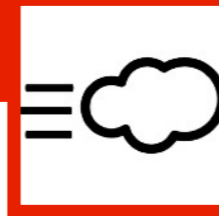
 PROBA2/SWAP



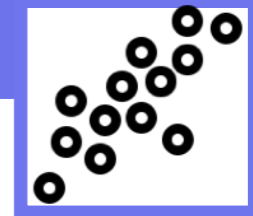
E.M. WAVES



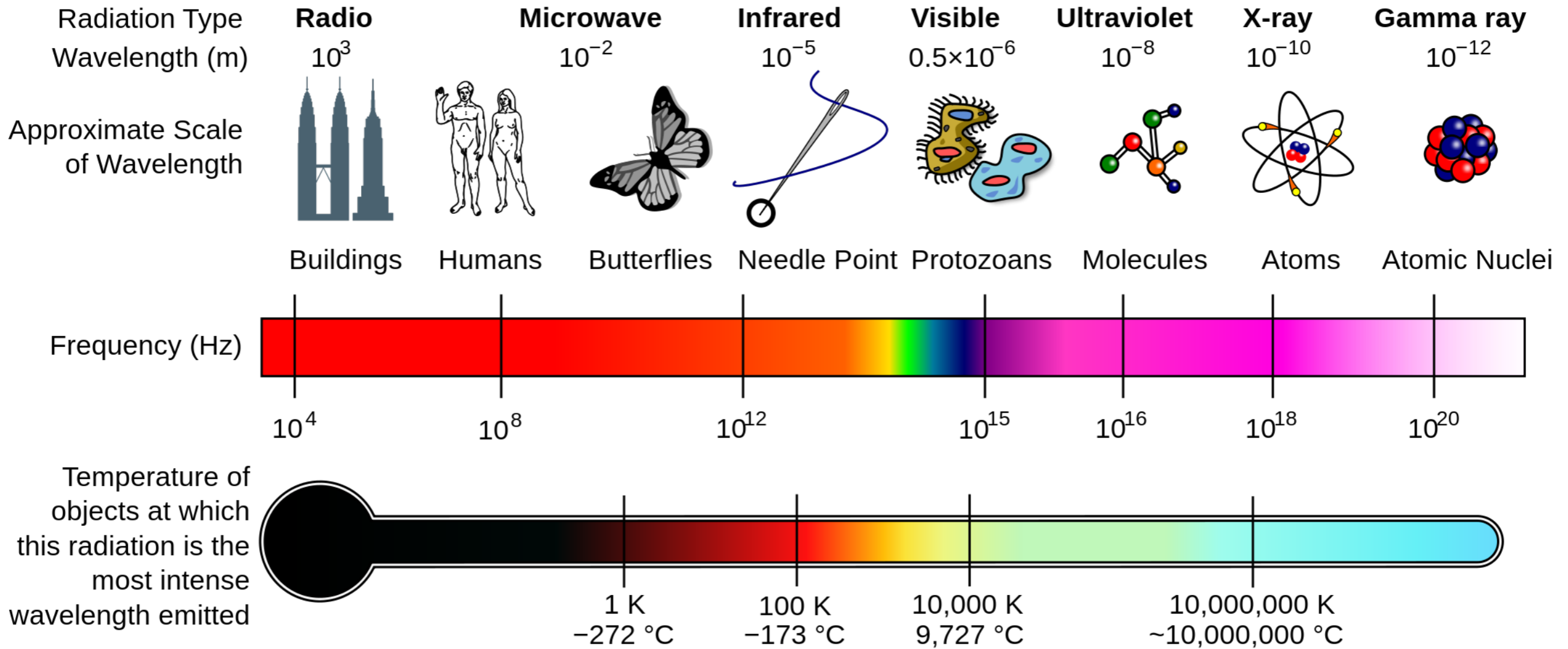
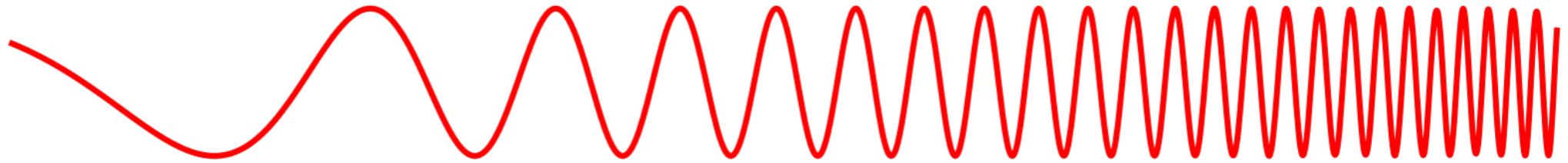
SOLAR WIND



SOLAR PARTICLES



E.M. WAVES



INTERPLANETARY MAGNETIC FIELD

An enormous amount of magnetic energy is stored in the Sun. The magnetic field is not only contained in the interior of the Sun but is present every where in the heliosphere.

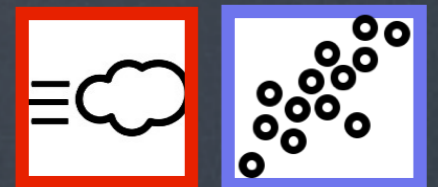


Image: Siberia 20080801

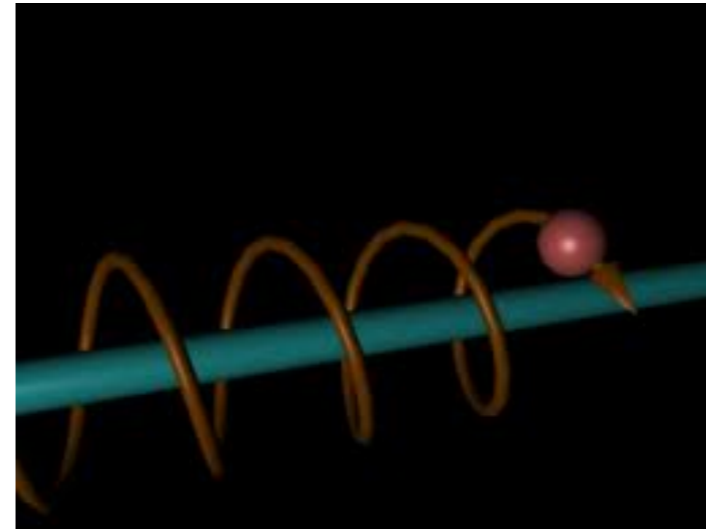
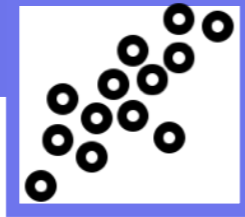
J.M.P., W. G. Wagner and H. Druckmüllerová

SOLAR WIND



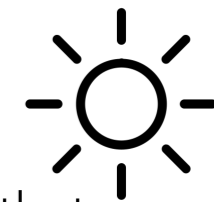
Solar wind shapes the Interplanetary Magnetic Field.

SOLAR PARTICLES

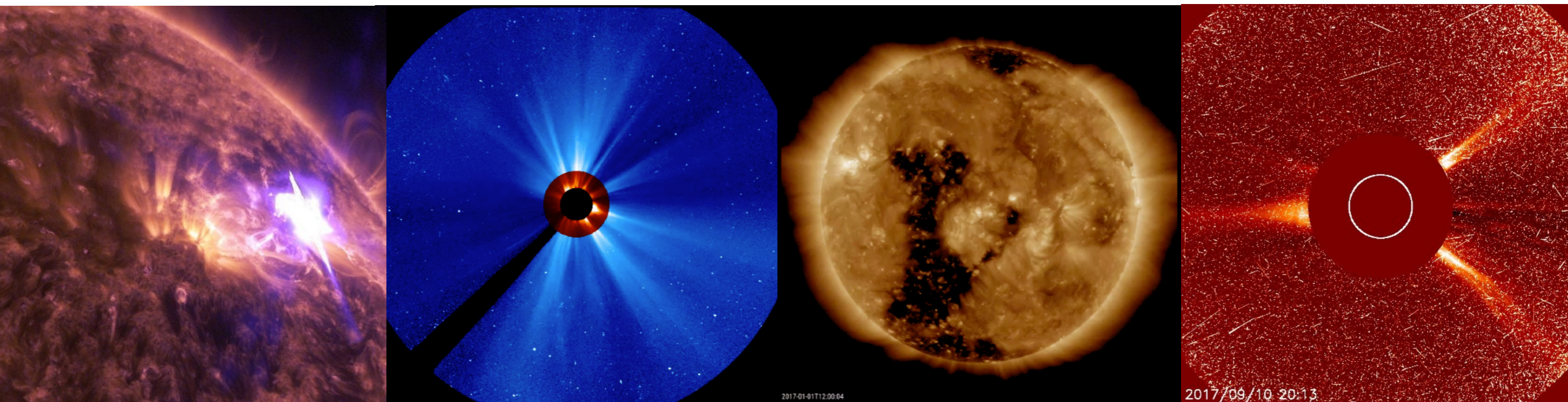


Solar particles are guided by the IMF.

SOLAR STORMS



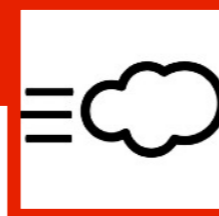
At a certain moment, energy might be released on a shorter time scale. A solar storm is the change that occur on the Sun or in the solar atmosphere. This chance might be in an abrupt, impulsive and brutal way (flare, Coronal Mass Ejection or CME, proton storm) or in a non-eruptive manner (Coronal Hole - CH).



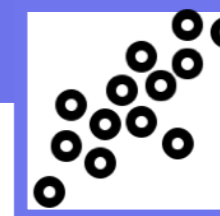
FLARE

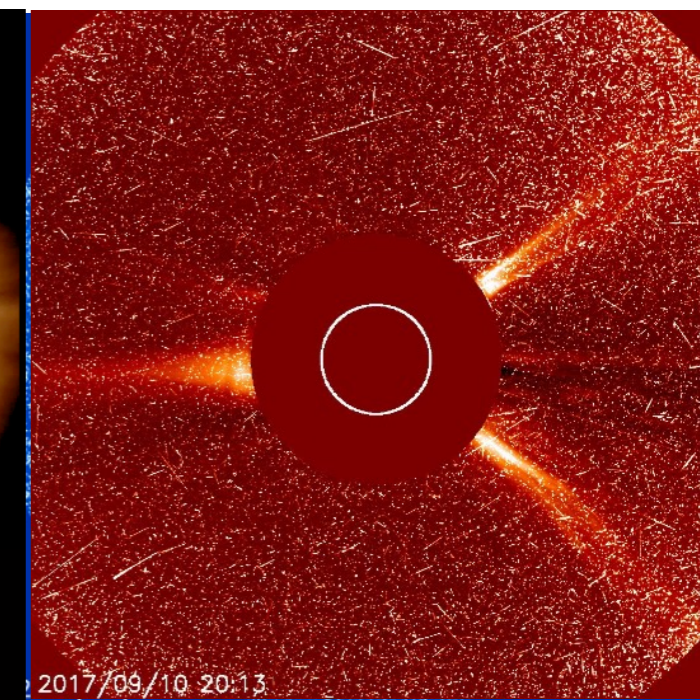
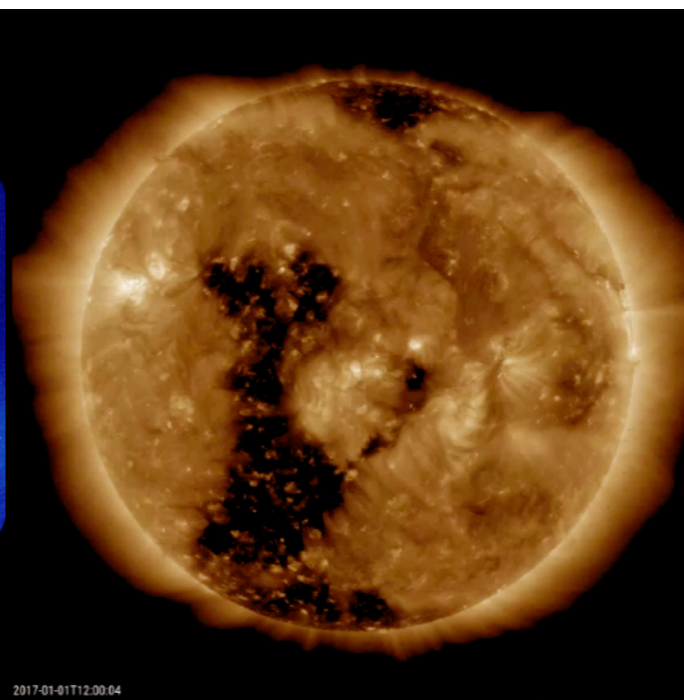
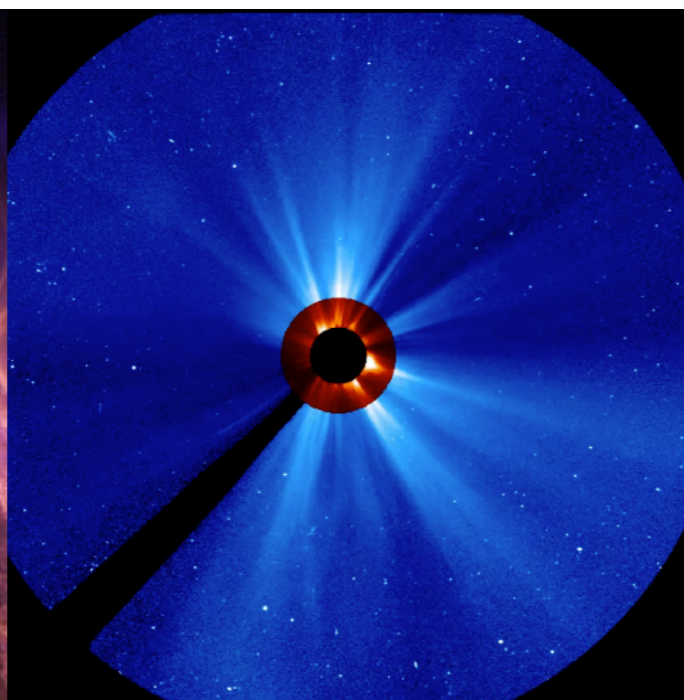
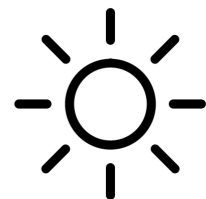


CORONAL MASS
EJECTION
CORONAL HOLE



PARTICLE STORM

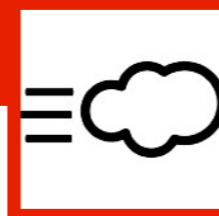




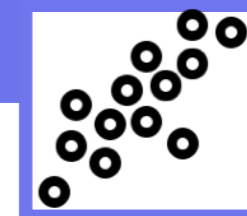
FLARE



CORONAL MASS
EJECTION
CORONAL HOLE

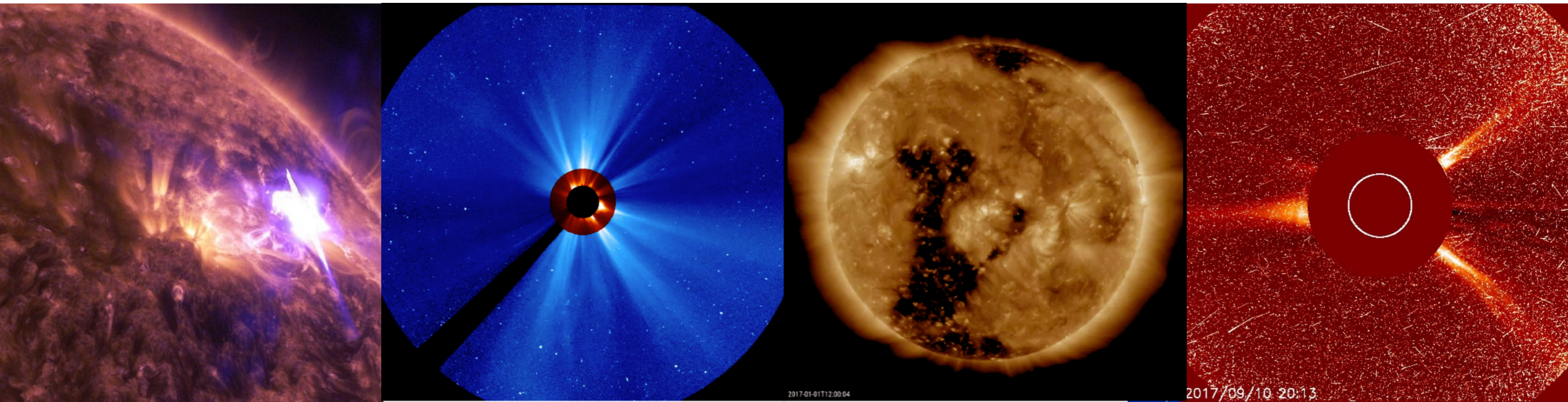
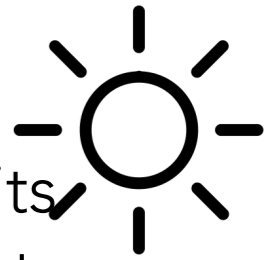


PARTICLE STORM



AU TRANSIT TIME

The energy released during a solar storm moves through space, each with its own typical speed: speed of light, order of a few 100 km/s, relativistic speeds.



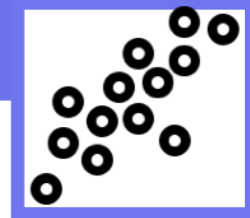
8 MIN



DAYS



HOUR



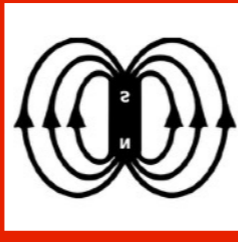
SPACE WEATHER

Our atmosphere and magnetosphere can respond in a dramatic way to solar storms. A solar storm can initiate space weather processes in our atmosphere and magnetosphere. This impact is measured near or on Earth and results in 3 sorts of space weather storms.

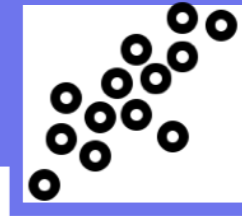
Radio blackout



Geomagnetic storm



Solar radiation storm



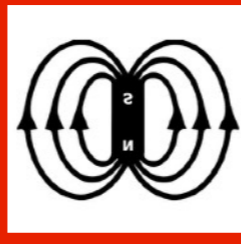
AREA OF IMPACT

Note that the solar wind can change the geomagnetic field by reconnection processes and by adding pressure. Reconnection is possible because the solar wind is magnetised. Charged particles follow simply the magnetic highways.

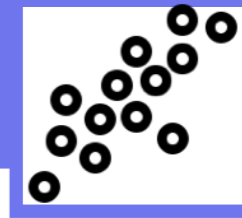
Illuminated area



Latitude

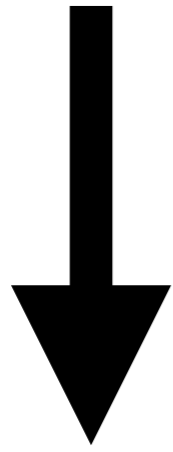


Latitude
Altitude



BREAK

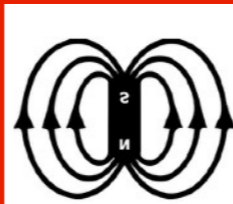




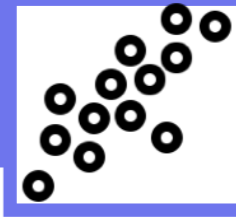
Radio blackout



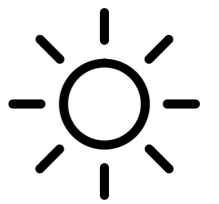
Geomagnetic storm



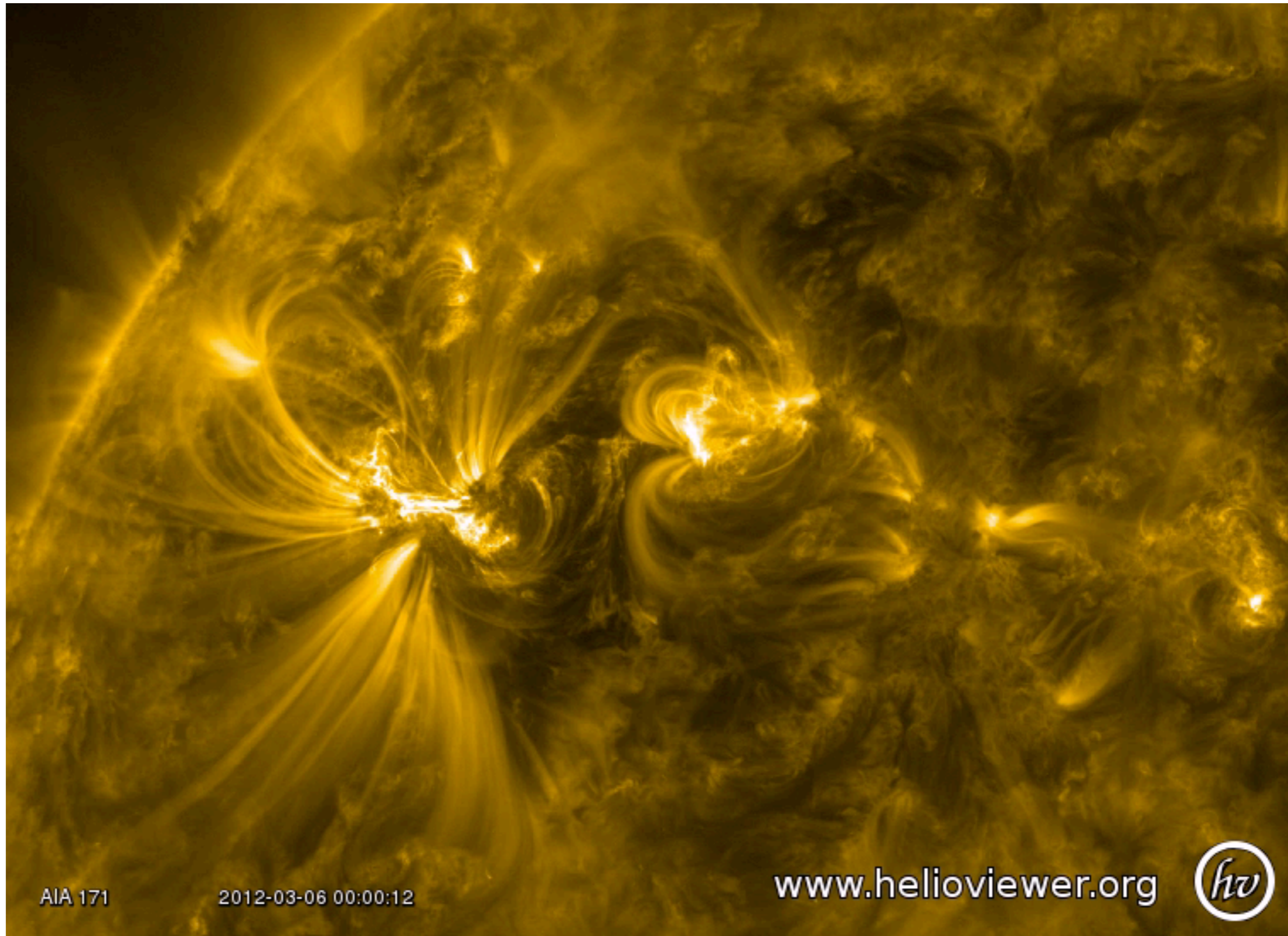
Solar radiation storm



SOLAR FLARES



A flare is a light flash near an active region. A volume of plasma is suddenly heated and therefore lights up.



SDO/AIA

AIA 171

2012-03-06 00:00:12

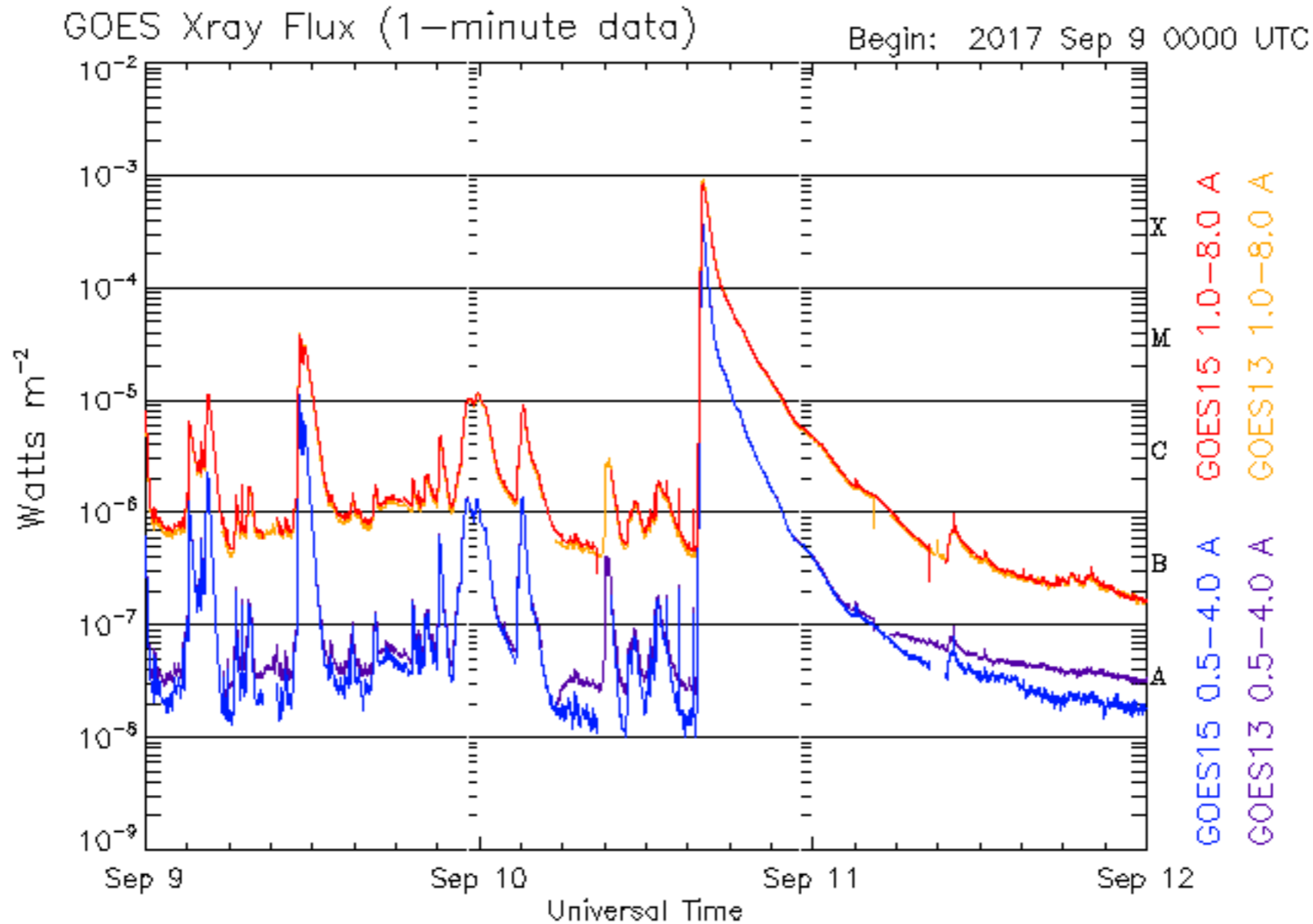
www.helioviewer.org





FLARE CATEGORIES & SW SCALES

A flare is identified by its x-ray flux. Flares are put into logarithmisch categories.



Updated 2017 Sep 11 23:59:12 UTC

NOAA/SWPC Boulder, CO USA





The impact of a flare depends on the intensity of the x-ray flux.

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	<u>HF Radio:</u> Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. <u>Navigation:</u> Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Fewer than 1 per cycle
R 4	Severe	<u>HF Radio:</u> HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. <u>Navigation:</u> Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	<u>HF Radio:</u> Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. <u>Navigation:</u> Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	<u>HF Radio:</u> Limited blackout of HF radio communication on sunlit side of the Earth, loss of radio contact for tens of minutes. <u>Navigation:</u> Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R 1	Minor	<u>HF Radio:</u> Weak or minor degradation of HF radio communication on sunlit side of the Earth, occasional loss of radio contact. <u>Navigation:</u> Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.

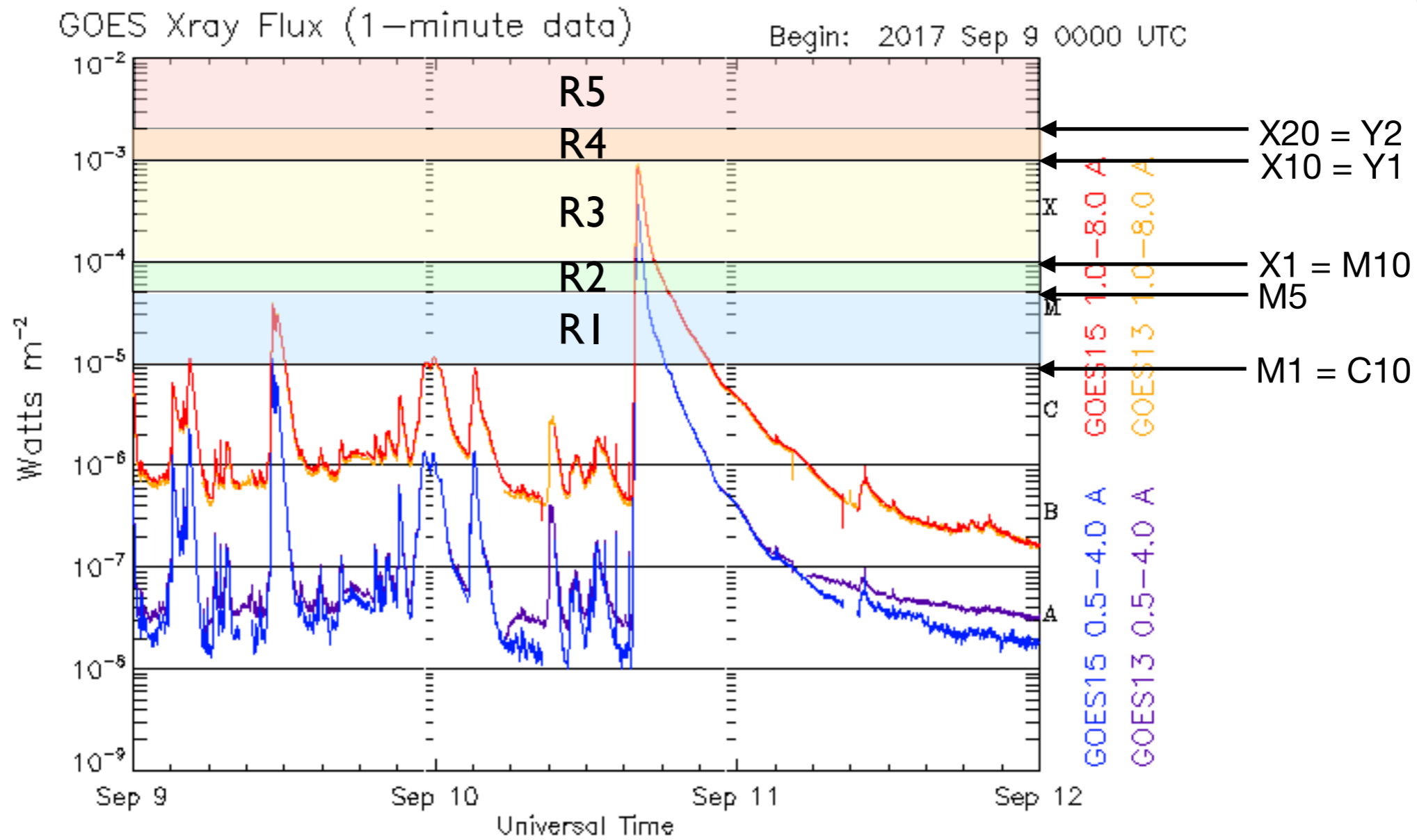
** Other frequencies may also be affected by these conditions.

URL: www.swpc.noaa.gov/NOAAscales

April 7, 2011



FLARE CATEGORIES & SW SCALES



Updated 2017 Sep 11 23:59:12 UTC

NOAA/SWPC Boulder, CO USA



X-RAY FLUX NOW

Flare



<https://www.swpc.noaa.gov/products/goes-x-ray-flux>



GOES

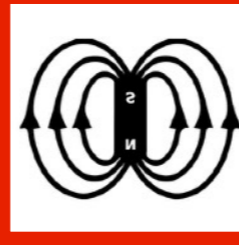




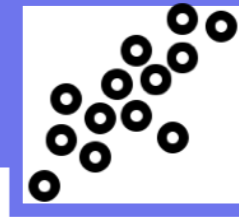
Radio blackout



Geomagnetic storm

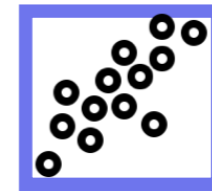
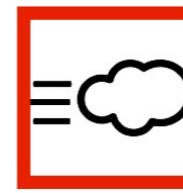


Solar radiation storm



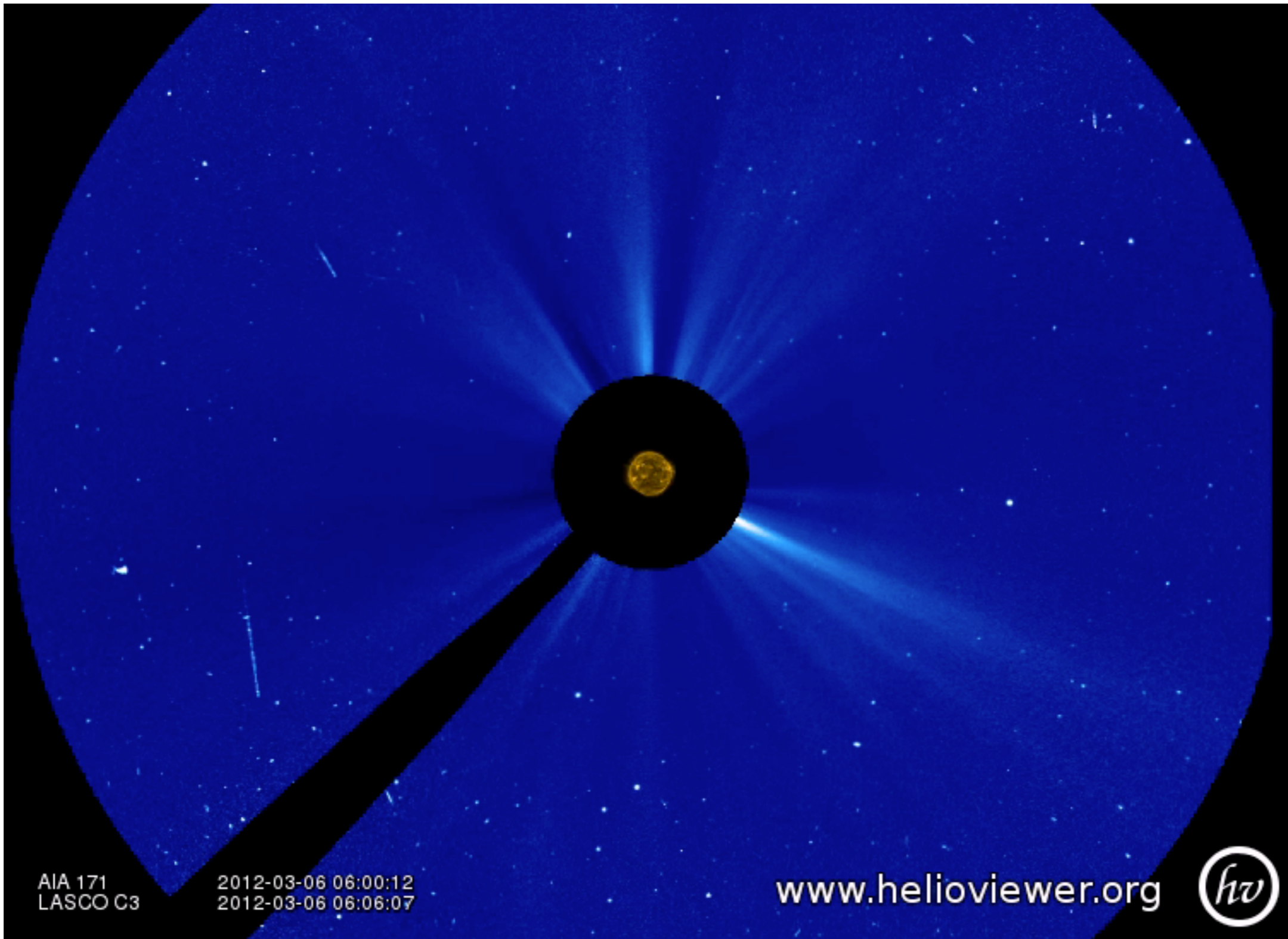
SOLAR STORMS

A solar cloud hurling through space. Solar particles hit the coronagraph.



SOHO/LASCO

SDO/AIA

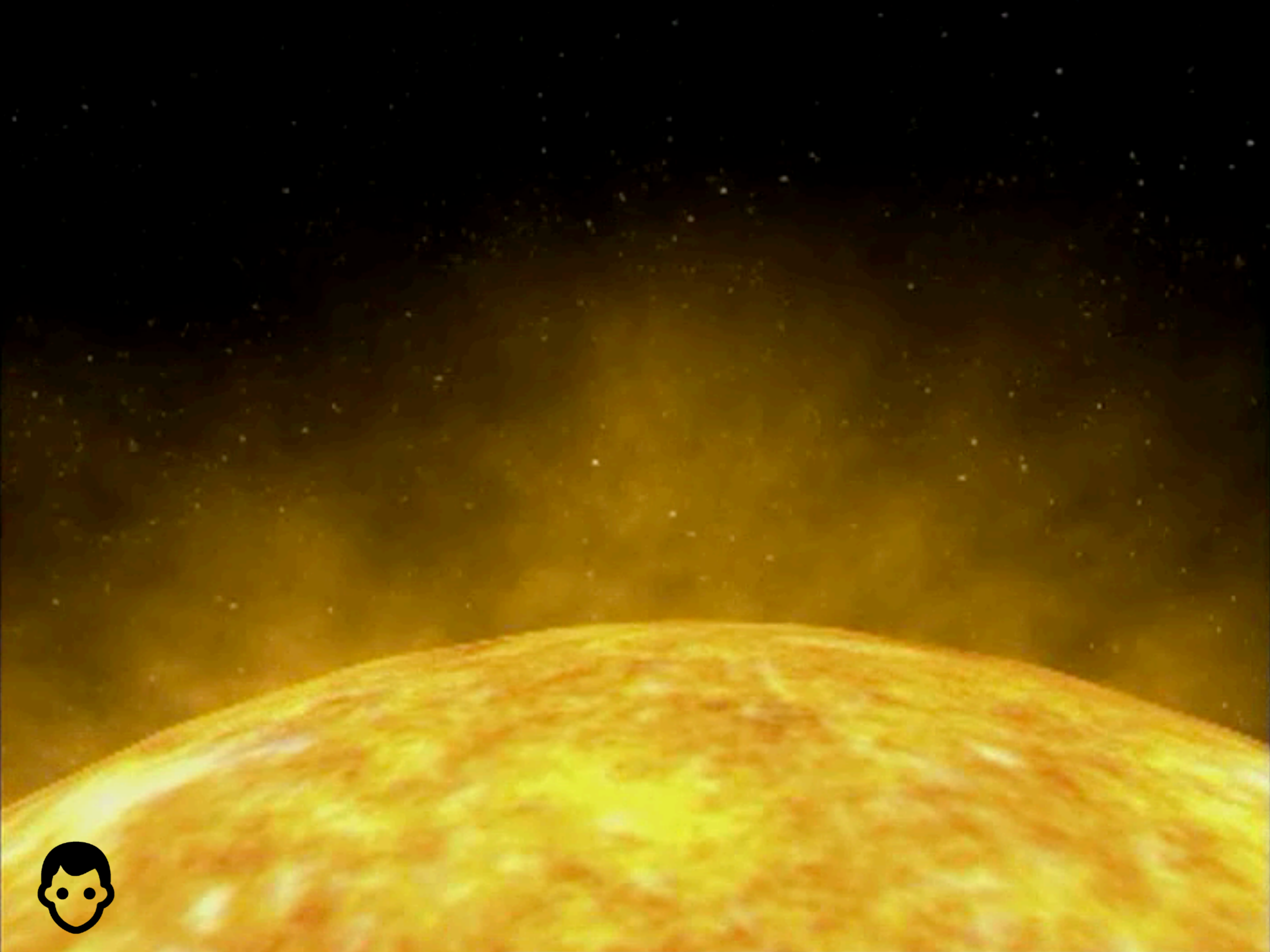


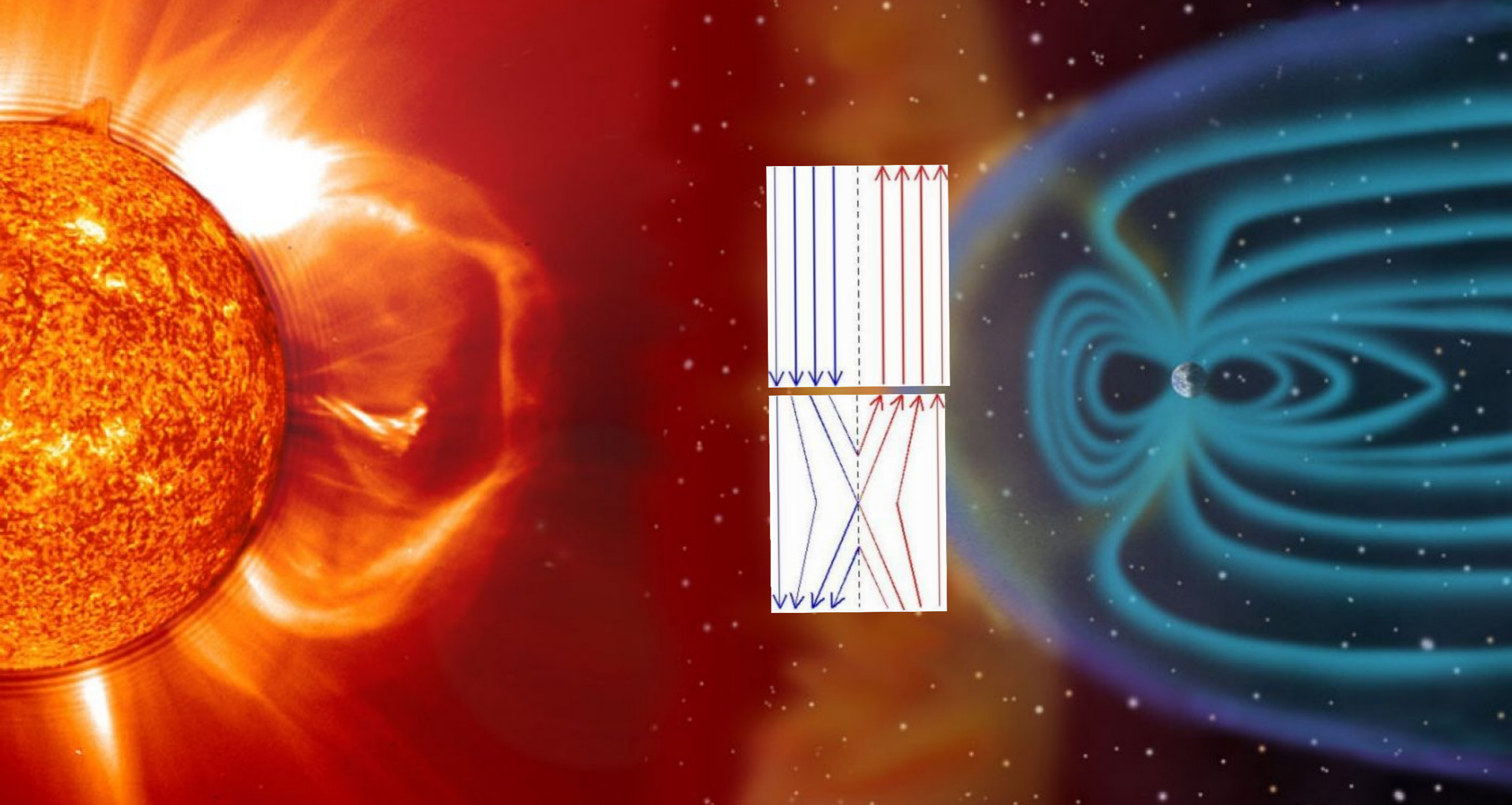
AIA 171
LASCO C3

2012-03-06 06:00:12
2012-03-06 06:06:07

www.helioviewer.org



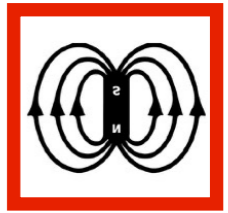




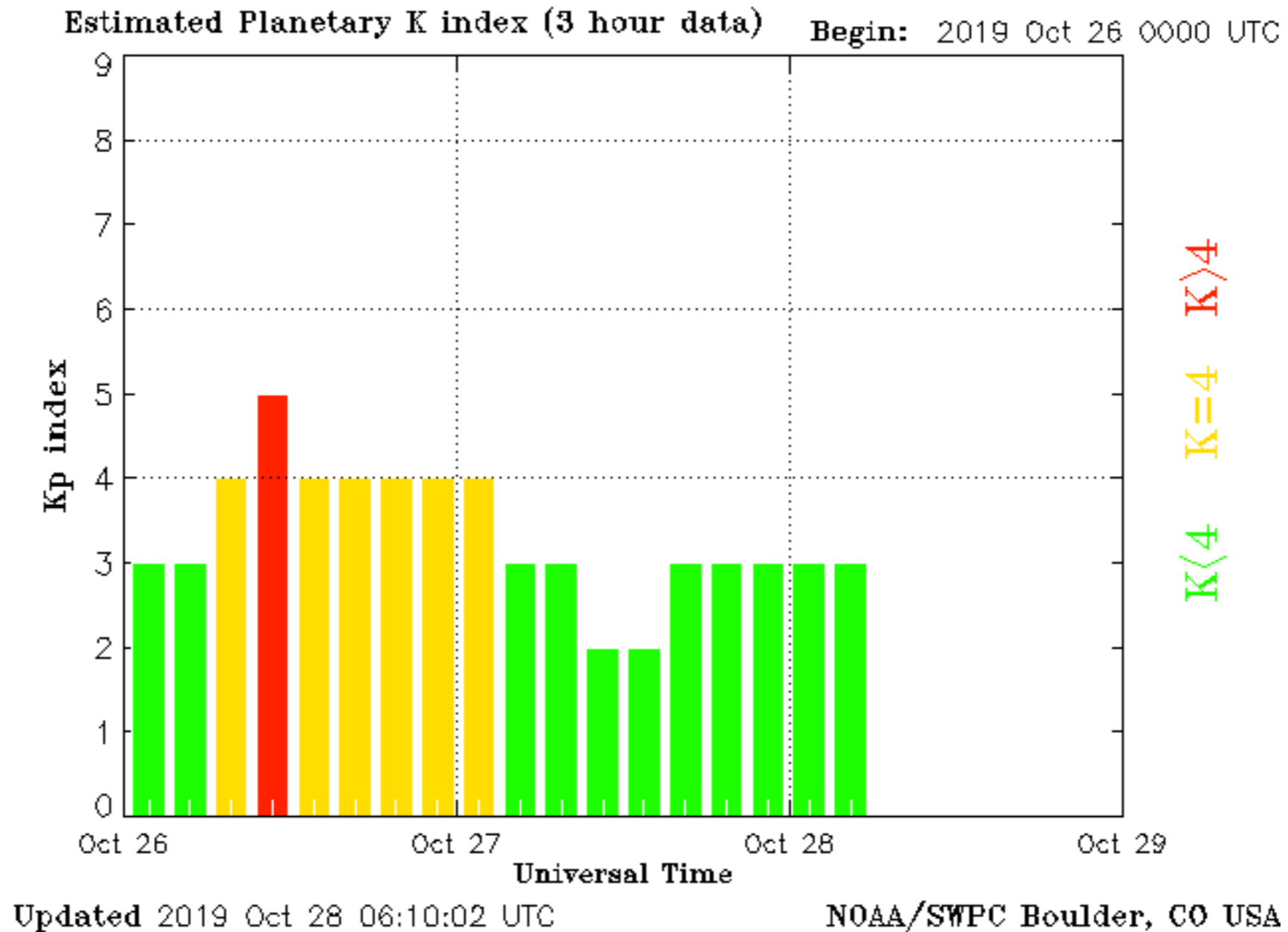
RECONNECTION

The magnetic field carried by the solar wind can couple with the magnetic field of Earth. This coupling is stronger when the solar wind magnetic field is opposite to the magnetic field of Earth.

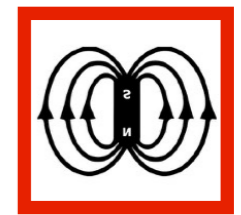
GEOMAGNETIC STORM



The effect of a geomagnetic storm depends on how strong the geomagnetic field is disturbed. This is described by an index Kp. This is an index that describes the conditions of the geomagnetic field at planetary level.



NOAA SPACE WEATHER SCALES

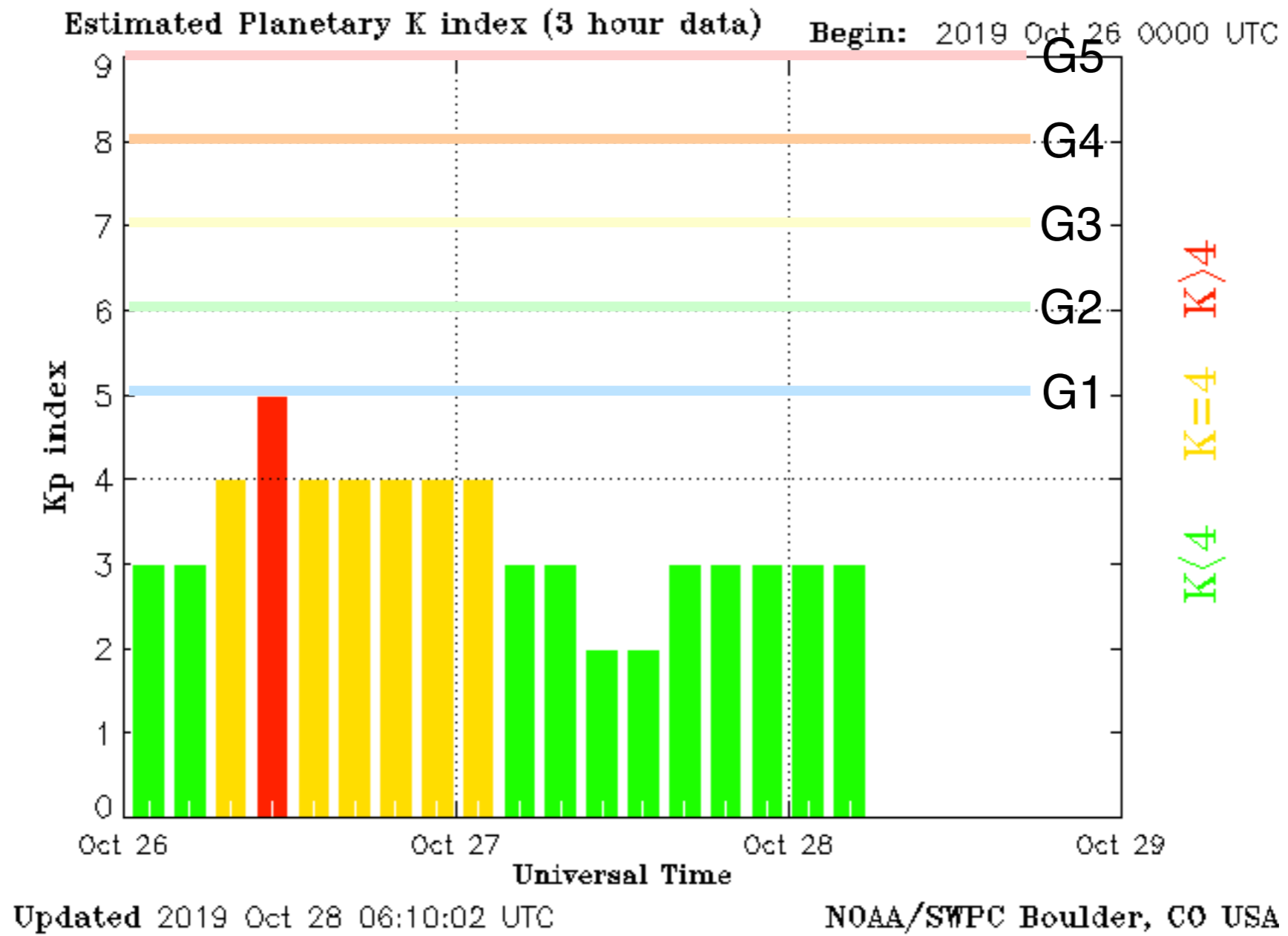
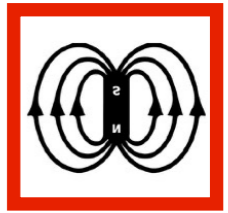


Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	<p><u>Power systems</u>: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage.</p> <p><u>Spacecraft operations</u>: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites.</p> <p><u>Other systems</u>: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).**</p>	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	<p><u>Power systems</u>: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid.</p> <p><u>Spacecraft operations</u>: may experience surface charging and tracking problems, corrections may be needed for orientation problems.</p> <p><u>Other systems</u>: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).**</p>	Kp=8	100 per cycle (60 days per cycle)
G 3	Strong	<p><u>Power systems</u>: voltage corrections may be required, false alarms triggered on some protection devices.</p> <p><u>Spacecraft operations</u>: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems.</p> <p><u>Other systems</u>: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).**</p>	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	<p><u>Power systems</u>: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage.</p> <p><u>Spacecraft operations</u>: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions.</p> <p><u>Other systems</u>: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).**</p>	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	<p><u>Power systems</u>: weak power grid fluctuations can occur.</p> <p><u>Spacecraft operations</u>: minor impact on satellite operations possible.</p> <p><u>Other systems</u>: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).**</p>	Kp=5	1700 per cycle (900 days per cycle)

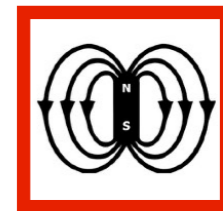
* Based on this measure, but other physical measures are also considered.

** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.swpc.noaa.gov/Aurora)

GEOMAGNETIC STORM DESCRIBED BY KP



GEOMAGNETIC STORM - KP INDEX NOW



<https://www.swpc.noaa.gov/products/planetary-k-index>





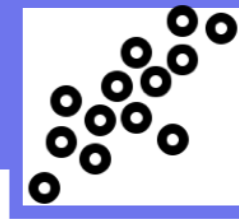
Radio blackout



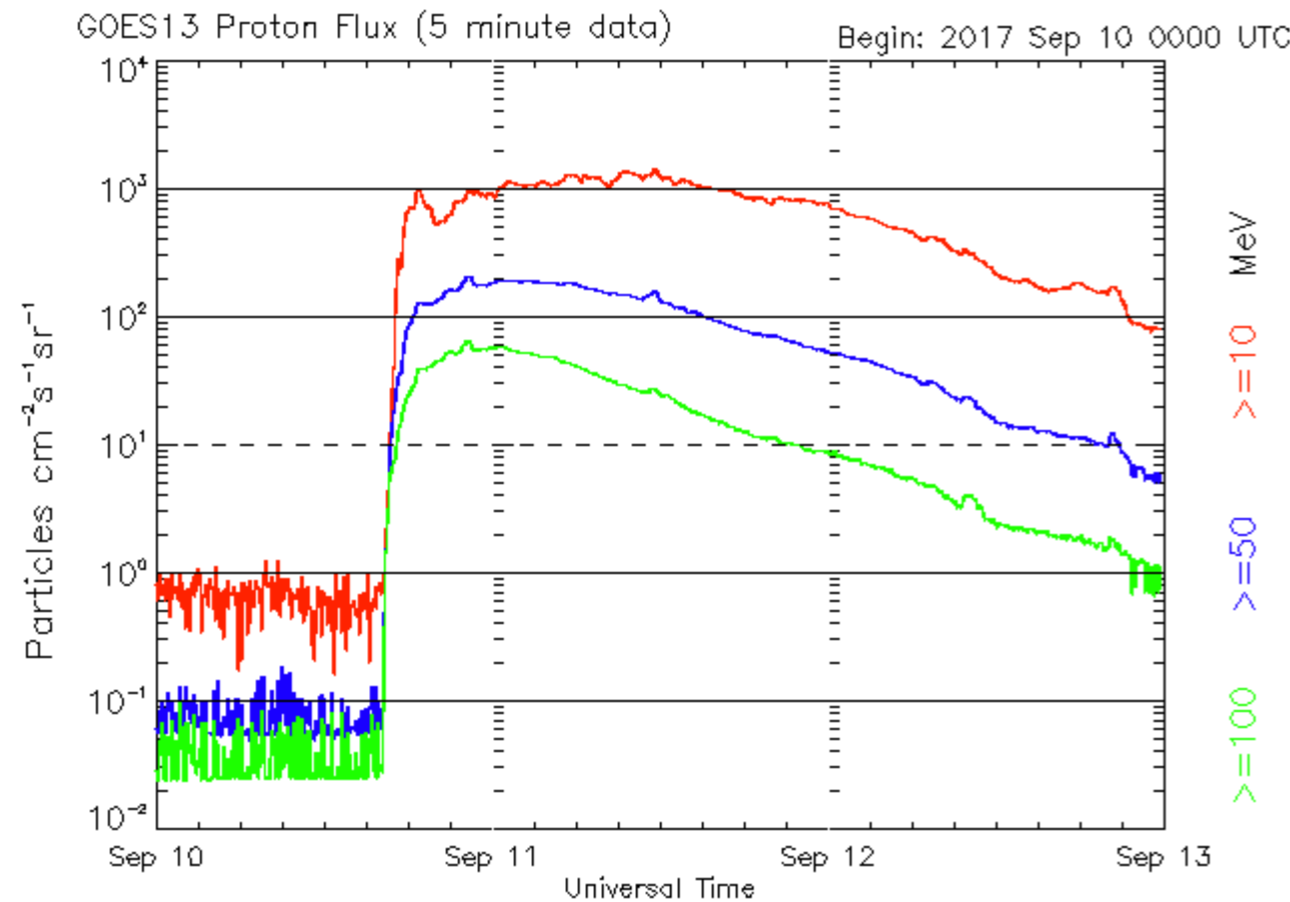
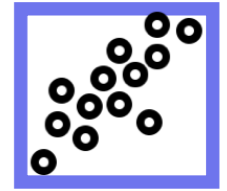
Geomagnetic storm



Solar radiation storm

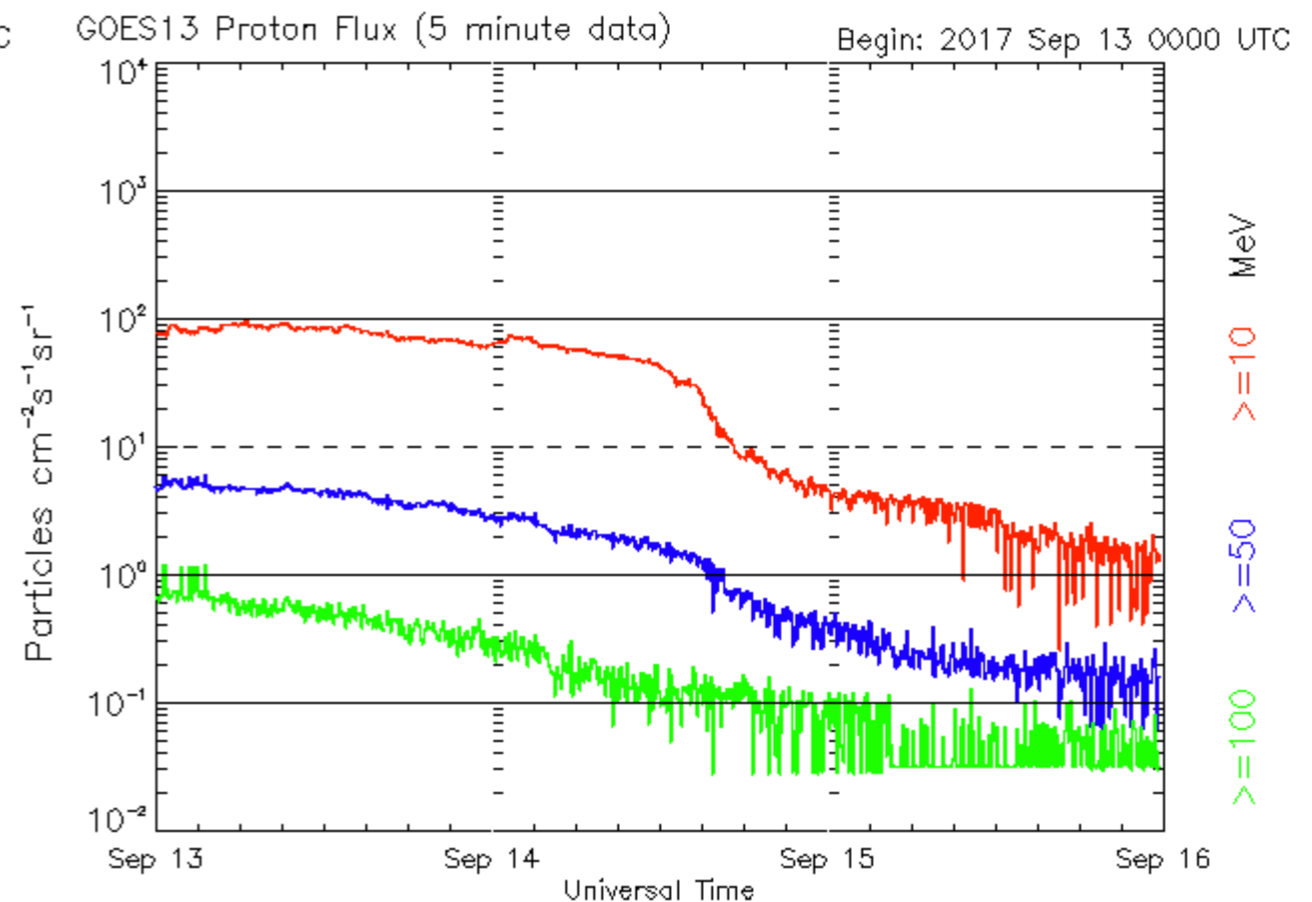


PROTON FLUX BY GOES



Updated 2017 Sep 12 23:56:02 UTC

NOAA/SWPC Boulder, CO USA

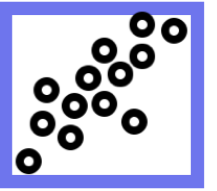


Updated 2017 Sep 15 23:56:01 UTC

NOAA/SWPC Boulder, CO USA



NOAA SPACE WEATHER SCALES



The impact energetic particles depends on the flux of the stream of particles.

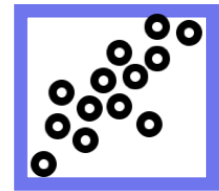
Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	<p><u>Biological</u>: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. ***</p> <p><u>Satellite operations</u>: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible.</p> <p><u>Other systems</u>: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.</p>	10^5	Fewer than 1 per cycle
S 4	Severe	<p><u>Biological</u>: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.***</p> <p><u>Satellite operations</u>: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded.</p> <p><u>Other systems</u>: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.</p>	10^4	3 per cycle
S 3	Strong	<p><u>Biological</u>: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.***</p> <p><u>Satellite operations</u>: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely.</p> <p><u>Other systems</u>: degraded HF radio propagation through the polar regions and navigation position errors likely.</p>	10^3	10 per cycle
S 2	Moderate	<p><u>Biological</u>: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.***</p> <p><u>Satellite operations</u>: infrequent single-event upsets possible.</p> <p><u>Other systems</u>: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.</p>	10^2	25 per cycle
S1	Minor	<p><u>Biological</u>: none.</p> <p><u>Satellite operations</u>: none.</p> <p><u>Other systems</u>: minor impacts on HF radio in the polar regions.</p>	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s⁻¹·ster⁻¹·cm⁻² Based on this measure, but other physical measures are also considered.

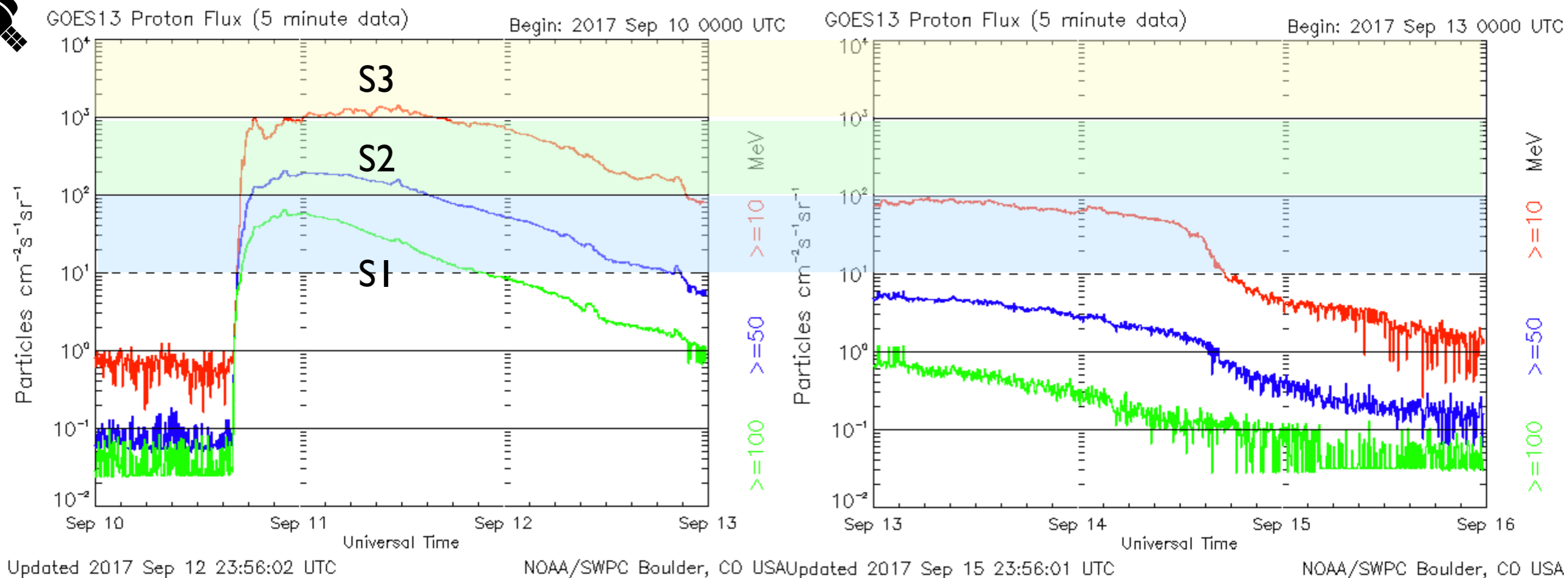
** These events can last more than one day.

*** High energy particle (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.





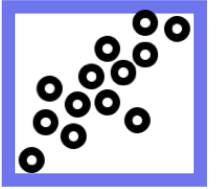
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